AD_________________

Award Number: W81XWH-10-1-0084

TITLE:
Anthro-Centric Multisensory Interface for Vision Augmentation/Substitution)

PRINCIPAL INVESTIGATOR:
Anil Raj, MD

CONTRACTING ORGANIZATION:
Florida Institute for Human and Machine Cognition
Pensacola, FL, 32502

REPORT DATE:
FEBRUARY 2011

TYPE OF REPORT:
Annual

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT:

☒ Approved for public release; distribution unlimited

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
14-02-2011

2. REPORT TYPE
Annual

3. DATES COVERED *(From - To)*
15 Jan 2011 – 31 JAN 2011

4. TITLE AND SUBTITLE
Anthro-Centric Multisensory Interface for Vision Augmentation/
Substitution

5a. CONTRACT NUMBER

5b. GRANT NUMBER
W81XWH-10-1-0084

5c. PROGRAM ELEMENT NUMBER
W81XWH-BAA08-1

6. AUTHOR(S)
Anil K. Raj, MD

araj@ihmc.us

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Florida Institute for Human and
Machine Cognition
40 South Alcaniz Street
Pensacola, FL 32502

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Telemedicine and Advanced
Technology Research Center

10. SPONSOR/MONITOR'S ACRONYM(S)
TATRC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
During year one of the Anthro-Centric Multisensory Interface Vision Augmentation/Substitution (ACMI-VAS) project, the research team developed an integrated system that can substitute tactile stimulation for visual stimulation to mimic the function of the retina. The ACMI-VAS concept uses a video camera connection to, or data from, a computer to represent, tactually, high resolution narrow field, mid resolution wider field and low resolution 360 degree visual information simultaneously. We will complete the testbed hardware and software in year two of the project and complete a experimental protocol to test the usefulness of the integrated system against a single tactile display for those (military and civilian) with profound blindness. Tasks will include reading, visual acuity, web browser navigation, walking an obstacle course and identifying colors.

15. SUBJECT TERMS
Blindness, human machine interface, sensory substitution, tactile interfaces

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Anil K. Raj, MD
a. REPORT	b. ABSTRACT	c. THIS PAGE	Distribution unlimited	21	19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified			850-202-4456

Table of Contents

Introduction

Servicemembers who suffer combat, training or accidental injuries that damage their sensory capabilities can have great difficulty returning to productive lifestyles once healed from their initial trauma. Sudden loss of vision can overwhelm a previously healthy individual's ability to interact with the world, adversely impact the individual's recovery from physical and emotional trauma, and preclude a return to the community as a productive, stable member of society. This project seeks to advance technologies for non-invasive vision sensory substitution and augmentation in order to allow these individuals to return to more normal social interactions. This project exploits two specific capabilities of the human central nervous system, namely cross-modal sensory interactions and brain plasticity, to address the needs of these injured servicemembers. Perception takes place in the brain, not at the end organ (Bach-y-Rita, 1972); therefore, the brain can learn to reinterpret the meaning of signals from specific nerves (e.g., from tactile receptors) given appropriate self-generated feedback. This forms the basis for interfaces that can non-invasively and unobtrusively use alternative sensory pathways to provide information. The Florida Institute for Human and Machine Cognition (IHMC) will develop a proof of concept prototype Anthro-Centric Multisensory Interface for Vision Augmentation/Substitution (ACMI-VAS) system. We envision that with appropriate development, the ACMI-VAS concept could be integrated and reduced in size to provide a robust situation awareness (SA) of visual information during activities of daily living.

Body

Sudden loss of vision can overwhelm a previously healthy individual's ability to interact with the world, adversely impact the warfighter's recovery from physical and emotional trauma, and preclude a return to the community as a productive, stable member of society. Traumatic brain injury (TBI) can also induce loss of one or more sensory capabilities. Intermittent or permanent loss of veridical sensory information adversely affects SA, leading to an inability to perceive and comprehend the meaning of elements in the environment and to project their future states. Without accurate SA, one's ability to interact in a dynamically changing world diminishes (Endsley, 2000). The sequelae of TBI and somatic polytrauma suffered by this growing population may evolve over many months after injury, manifesting as significant loss of one or more sensory channels well after a traumatic event (Owens, 2008). While current technologies for noninvasive sensory substitution provide an inadequate replacement for lost sensory capabilities, they can augment residual sensation. In addition, when integrated with other substitution technologies, these technologies can improve SA, and therefore open opportunities to injured servicemembers that they might not otherwise investigate. This research and development project seeks to leverage a number of current technologies as well as some that are under development into a novel multi-sensory vision augmentation/substitution interface that will enable wounded servicemembers to regain some measure of normal visual interactions and functional return to activities of daily living.

Sensory loss can be addressed by using precisely positioned large magnetic fields (Kupers, et al., 2006) or surgically with implanted devices like cortical (Dobelle, 2000; Fernández, et al., 2005) and end organ stimulators such as cochlear or retinal implants (Zhou & Greenberg, 2005; Weiland, Liu & Humayun 2005; Veraart, et al., 2003; Maynard, Nordhausen & Normann, 1997; Rauschecker & Shannon, 2002), but this adds both surgical trauma and risk of infection (Reefhuis, et al, 2003). These devices require chronic indwelling implants (Figure 1) that, at the current state of the art only provide minimal resolution (e.g., to 20/120 equivalent vision, Dobelle, 2000), and in the case of cortical implants may induce seizures (Javaheri, et al., 2006; Kotler, 2002). While recent advances have dramatically increased resolution available from retinal implants (Zrenner, et al., 2010), they still require invasive surgery, indwelling foreign bodies and an intact oculus. Given the rapid development of modern electronics, wireless communications, batteries and computer technologies, it stands to reason that implanted devices will also continue to improve qualitatively rapidly and patients who receive implants will need to seriously consider the risks and benefits of “upgrading” their prostheses through more surgery. Servicemembers blinded from battlefield polytrauma will have likely endured multiple surgical procedures by the time they have stabilized sufficiently to consider a retinal or cortical implant and may not be candidates due to injury to underlying neural tissue (retina), pathways (optic nerve) or cortical processing (occipital lobe). An alternative solution to this form of sensory replacement, namely sensory substitution, has shown promise for blind individuals and can tolerate damage in any of these components that make up the “retinex” (Land, 1964) normally required for human perception of the visual environment.

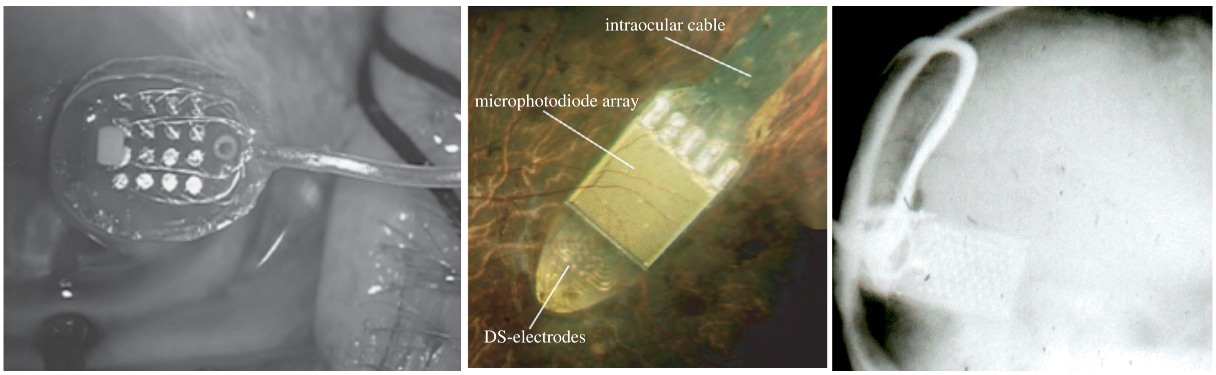

Figure 1: (*left)* Photograph of the Model 1 epiretinal microelectrode array (Second Sight Medical Products, Inc, Sylmar, CA) prior to insertion into the ocular vitreous cavity. (*center*) Retinal Implant AG (Reutlingen, Germany) subretinal combined photodiode/electrode array with 1500 sensors and electrodes. (*right)*, X-ray of implanted cortical array (Dobelle, 2000) positioned on the occipital cortex.

Perception takes place in the brain, not at the end organ (Bach-y-Rita, 1972); therefore, the brain can learn to reinterpret the meaning of signals from specific nerves (e.g., from tactile receptors) given appropriate self-generated feedback. This forms the basis for interfaces that can non-invasively and unobtrusively use alternative sensory pathways to provide information. This means that the information displayed does not necessarily need to represent the underlying data at high resolution, rather abstract representations of the sensory environment information can provide sufficient data for operator decision making and improved SA (Raj, Kass & Perry, 2000). Such sensory substitution mechanisms exploit the plasticity inherent to the brain and nervous system, supporting both long term and short term anatomical and functional remapping of sensory data (Finkel, 1990; Walcott & Langdon, 2001). Sensory substitution refers to the remapping of sensory data from the normal sensory receptor field for a particular type of data to other channels of information perception (Bach-y-Rita, Collins, Saunders, White & Scadden, 1969). With appropriate feedback, the plasticity of the human brain allows individuals to learn to perceive the substituted data with little cognitive effort, especially if training is provided soon after sensory loss (Bavelier & Neville, 2002). For maximal benefit, the interface must also intelligently pre-process the incoming data to account for differences in capability between the alternative channels and the ones normally used to perceive given sensory data, as well as provide intuitive control and data management. Many sensory substitution devices and approaches have been developed over the past decades (Machts, 1920). Modern computer and electronic design, however, now enables the development of intelligent, noninvasive interfaces unobtrusive enough for use in everyday activities.

Neural projections from the visual, auditory and proprioceptive sensory systems interact in the brainstem at the superior colliculus (Meredith & Stein, 1986; Wallace & Stein, 2000) and higher levels (Fort, et al., 2002), where mechanisms such as non-synaptic diffusion neurotransmission (as well as synaptic connections) can cross-modally engage different sensory channels (Bach-y-Rita, 1995). In addition, crossmodal activity has been demonstrated in the primary and secondary cortical processing areas for individuals with and without sensory impairment (Schroeder & Foxe, 2005). For example, deaf individuals show activation in the auditory cortex in response to visual stimuli (Finney, Fine & Dobkins, 2001), blind individuals show visual cortex activity in response to touch (Sadato, et al., 1996; Sadato, et al., 2004; Sathian, 2005) and vibratory stimuli (Burton, Sinclair & McLaren, 2004), and auditory stimuli can elicit changes in somatosensory cortex activity (Foxe, et al., 2000). The fact that these interactions exist and become more pronounced given sensory channel deprivation (Sathian, K., 2005) supports the use of sensory substitution as a potential solution for partial restoration of lost sensory channels.

With veridical multisensory information, these mechanisms appear to enhance perception accuracy and reaction time (Deiderich, 1995), as well as modulate ongoing cognitive processes (Schroeder & Foxe, 2005) while improving workload performance and SA (Wickens & Holland, 1999). By exploiting this cortical crossmodal integration (Calvert, 2001), we and other researchers have shown that individuals with sensory loss due to artificial restrictions, disease, congenital defect, or injury can use sensory substitution interfaces to exploit this inherent plasticity of the brain and nervous system for both long term and short term anatomical and functional remapping of sensory data (Walcott & Langdon, 2001; Ptito, Moesgaard, Gjedde & Kupers, 2005; Kaczmarek, Bach-y-Rita, Tompkins & Webster, 1985) and improvement in SA (Raj, Kass, & Perry, 2000; Saunders, Hill & Franklin, 1981). Recent brain imaging studies have confirmed crossmodal modulation of activity across different sensory cortices that varies depending on whether multiple sensory channels provide congruent information or incongruent information (Johnson & Zatorre, 2005; Jones & Callan, 2003; Fort, et al., 2002; Laurienti, et al., 2002). Because attentional resources or cognitive effort required to process the sensory channel data also manifests as intersensory cortical activity modulation (Loose, et al., 2003; Kanwisher & Wojciulik, 2000; van Wassenhove, Grant & Poeppel, 2005; Mozolic, et al, 2008), multisensory aids for the blind must minimize sensory display complexity to reduce cognitive demands.

A number of options for visual sensory substitution exist, however, the two most investigated methods use audio and tactile representations, respectively, of visual information. The Braille tactile alphabet represents the most common example of tactile substitution using two columns of six or eight raised bumps either embossed on paper or presented using a mechanical device. While this has worked well for plain text transcriptions, it becomes unwieldy for graphical information for technical information such as mathematical formulas (Moço & Archambault, 2003) and the graphically rich visuals of magazines, the Internet and the natural world. (Boehm, 1986; Ifukube, Sasaki & Peng, 1991). An alternative technique promoted by Meijer (1992) called “The vOICe“ system converts images into an audio time multiplexed frequency and amplitude representation that sweeps across successive frames of video to encode spatial information into a complex audio stream (Amedi, et al., 2005). The biggest drawback to these systems related to the amount of training required to become fluent in the alternative representation and the fact that these methods heavily engage the remaining senses. With Braille, the reader’s hands are unable to perform other activities of daily living (such as making a sandwich). The vOICe system audio display and computerized text to speech screen readers such as Job Access With Speech (JAWS®, Freedom Scientific, Inc., St. Petersberg, FL) (Bryant & Bryant, 2003) as well as more recent multimodal computer interfaces for the blind (Yu, et al., 2006) require significant auditory cognitive engagement and may prevent accurate sensing of events in the ambient acoustical environment (e.g., a ringing telephone). Portable camera based readers such as the knfbReader Mobile (K-NFB Reading Technology, Inc., Newton Lower Falls, MA) allow the blind to carry optical character recognition into the real world, but camera resolution and lack of context of the visual environment (Gaudissart, et al., 2005) make such systems fairly cumbersome to use in practice (e.g., the user does not have a sense of the size of the type or if there is any text to recognize without additional input from a sighted individual).

The Florida Institute for Human and Machine Cognition (IHMC) has, therefore, focused on integration and development of non-invasive methods of presenting visual information to blinded servicemembers using sensory substitution. By leveraging previous work for the United States Navy and the National Aeronautics and Space Administration (NASA) originally designed to enhance SA for aviators and astronauts, along with modern tactile technologies designed for the blind, we have developed prototype hardware components that could provide a substantial level of visual sensory information. With early versions of these components, we have provided partial demonstrations to and solicited early feedback from four recently blinded military servicemembers. These evaluators suffered polytraumatic injuries that resulted in enucleation of both eyes 10-48 months prior to participation. All had and at least one ocular prosthetic fitted. Two existing tactile interfaces were demonstrated, the U. S. Navy/NASA/IHMC Tactile Situation Awareness System (TSAS) and the video camera based Wicab, Inc., (Middleton, WI) BrainPort® Wearable Aid for Vision Enhancement (BP-Wave II). The former provided a limited sense of peripheral visual object detection using 24 electromechanical vibro-tactile transducers (tactors) mounted in a garment that creates a three-dimensional tactile torso interface (TTI) array on the body. The latter consisted of an 18x18 array of electrotactile tactile transducers placed on the user's tongue in a two dimensional array (Figure 2).

Figure 2: Blind servicemembers using prototype sensory substitution interfaces. (*left*) Using the TTI to receive peripheral attention directing tactile cues. (*center left*) Using the BP-WAVE II to negotiate stairs without assistance and (*center right*) to read text. (right) BrainPort® Intraoral Device electrotactile tongue array (600 tactile pixels).

With these systems we have demonstrated awareness of nearby objects on the torso and, through the BrainPort® tongue array, identification of shapes, shape orientations, reading (up to 4-5 word sentences), catching balls rolled across a table, navigating unfamiliar office spaces, negotiating stairs, identifying open parking stalls from ones with vehicles, performing standard visual acuity tests to 20/40 equivalent using standard eye charts and identifying features of family members (Figure 3). At most, each individual performed these tasks with 4-6 hours of total training time.

Figure 3: Initial BP-WAVE II activities performed during technology demonstrations with recently blinded servicemembers. *left to right, top to bottom*, Catching balls, navigating office spaces, locating open parking stalls, noticing infant's hair, and reading eye charts to 20/80 (*images used with permission*).

In addition, IHMC has demonstrated that a direct connection between the tactile interface and a computer graphical display can provide a superior qualitative experience by bypassing the limitations of cameras (e.g., glare, changing lighting conditions, focus and unintentional movements of the head). While this direct connection removes the need to position the user in front of a computer (a useful capability for those with orthopedic or other injuries that prevent prolonged upright posture), we have prototyped two methods of tactile computer interactions that mimic sighted interactions. Using video oculography, we have demonstrated that blind individuals can use extraocular musculature to control insensate eyes (even prosthetic ones) with sufficient accuracy to pan and scan to read across an image presented tactually. Likewise, head position can control image zoom such that a blind user can lean toward or away from an object of interest to zoom in or out. In the current implementation, looking away from the computer screen automatically switches to direct camera feed, which allows the user to look down at the keyboard when typing or observe other items in the environment. Alternatively, we have also implemented a touch screen mechanism that allows the user to feel the pixels under his or her fingertip via the tongue while dragging across the screen (Figure 4). Both mechanisms have been mastered by participants in less than 30 minutes, indicating that the method does not significantly task cognitive resources.

Figure 4: Direct computer tactile (BrainPort®) interface demonstrations. *left*, participant prepares to use eye/head tracking apparatus to determine point of gaze despite the users' prosthetic eyes. The software determines if the participant is looking at the screen and returns a 100-200 pixel sample of the screen image. The user intuitively controls zoom level by leaning either toward or away from the screen. Looking down automatically selects a gaze directed subsample of the video image from the head mounted camera (allowing the user to find keys on the keyboard). r*ight*, When the user touches the screen, the subsection of the screen image underneath the fingertip is presented to the tongue instead.

Two major issues were noted with the prototype system evaluations, namely registration of gaze position relative to the visual task and perception of changes in the environment outside the field of view of the camera. When reading, for example, inadvertent head and body movements caused the camera image to move away from the word or letter of interest. Reacquisition of the word or letter required additional panning and scanning in order to find the line of text and the word or letter. The lack of peripheral visual sensation appeared to cause a high level of anxiety for recently blinded individuals (who may not have yet adapted to their visual loss). Blind individuals are often startled when others approach quietly and begin talking to or make physical contact with them. These issues warranted the integration of additional displays and sensors to provide paracentral and peripheral visual information and a sense of gaze location within the broader visual context.

Following these initial technology demonstrations, IHMC aggregated these prototypes in order to improve a user's tactile visual sensory substitution perception. Using the BP-WAVE-II prototype and the previous generation VideoTact, we determined that tasks that required serial visual scan, such as reading, visual acuity testing, identifying shapes arrange in rows and columns, etc., could be performed more easily when using the two tactile interfaces simultaneously (Figure 5).

Figure 5: Initial mock up of ACMI-VAS for foveal and paracentral vision substitution. Image (upper right inset) presented on the VideoTact (upper left inset) is zoomed in less than the BrainPort® image zoom level (center display of lower right inset) to provide a slightly wider field of view. The physical size of the components has been reduced significantly and control of the combined technologies has also been simplified using IHMC's AMI architecture.

IHMC used its existing, in-house developed Adaptive Multiagent Integration (AMI) software architecture, which can easily connect components such as displays, sensors, algorithms and adaptive automation via a standardized Java (Sun Microsystems, Inc, Santa Clara, CA) interface. AMI associates explicit ontological definitions with each agent that allow rapid integration of new components (as software agents) into the architecture because the system identifies and makes data connections between agents automatically, based on data types and relative quality of similar data streams. The large complement of devices, including video, motion capture, tactile and audio interfaces, and pressure, orientation and psychophysiologic sensors, already been integrated as software agents (Johnson, et al., 2005) were leveraged and additional agents were created as needed. The architecture is inherently scalable, using available processing power and allows unlimited nodes and agents on wired or wireless networks. Communications between agents are made peer to peer and support high data rates and both secure and open transport mechanisms. Sensor signals or processed data can be delivered to multiple displays across different modalities (e.g., video, audio, vibrotactile, electrotactile, etc.) simultaneously or separately, enabling side-by-side real-time evaluation of various sensory substitution implementations (Raj, et al., 2005). Leveraging AMI for this project enabled rapid development of the ACMI-VAS prototype by taking advantage of existing software agents for a number of tactile interfaces (including torso, abdominal and tongue placed displays), various video cameras, peripheral range and bearing sensing, as well as head and eye tracking (e.g., OptiTrack, NaturalPoint, Inc., Corvallis, OR; RK-826y-BPCI, IScan, Inc., Burlington, MA).

By leveraging other funding vehicles following the initial technology demonstrations noted above, the ACMI-VAS system benefits from advances in the BrainPort®, the VideoTact and TTI (Figure 6). Notably, IHMC has acquired two BrainPort® V100 units to replace the prototype BP-WAVE-II units. We have collaborated with ForeThought Development, LLC, to design a more compact VideoTact system that utilizes modern electronics components.

Figure 6: (*left*) Current BrainPort® V100 system showing sunglasses mounted camera, handheld embedded processor/user input device and 400 tactor IOD. (*center*) TTI with ACU mounted C-2 tactors and (*right*) comparison of C-2 (gold) and C-3 (silver) tactor sizes.

Lastly, we have developed an reflected infrared sensor range and direction detection system that can detect objects in the environment and represent their locations and motion using the TTI (Figure 7), which can use the much smaller, lighter weight C-3 tactors versus the larger, older C-2 tactors (Engineering Acoustics, Inc., Casselberry, FL).

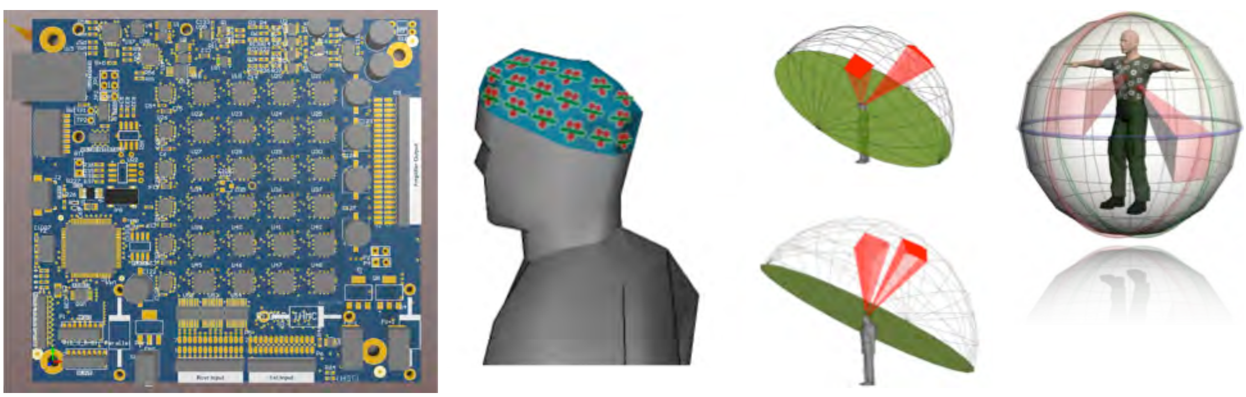

Figure 7: (*left*) IHMC's embedded microprocessor controlled 24 channel reflected infrared emission range and direction peripheral vision sensor PC-104 size circuit board. (*center left*) Schematic of head worn cap with embedded IR emitters and receivers detecting (*center right*) objects in the environment. (*left*) A second circuit board receives the signal and represents the information on the torso using the TTI.

These technology advances formed the basis of the ACMI-VAS central/paracentral and peripheral vision substitution concept. Because the V100 is now available as an investigational device for research applications, IHMC designed a study to compare blind performance on activities of daily living with the BrainPort® alone, or with ACMI-VAS (which includes the BrainPort® for foveal substitution, the VideoTact for parafoveal substitution, and the TTI for peripheral substitution).

In the first project quarter, primary efforts related to initial evaluation of hardware integration approaches for development of the multisensory "haptic retina" system. This included evaluation and modification of existing training protocols by the research staff and software modification to parse data from a single camera to multiple tactile displays at resolutions appropriate for each display. We integrated the current VideoTact display with older prototype 325 pixel BrainPort® devices. Two hardware issues arose in the first quarter that delayed initial integration. The first related to this VideoTact (ForeThought Development, LLC, Blue Mounds, WI) electrotactile abdominal display, which developed an intermittent issue that resulted in a system shutdown. This resulted from a safety shutdown whenever a signal was passed through a failed resistor array. Repair of this intermittent failure took approximately 8 weeks from onset to return of the device. The second issue related to the BrainPort® V100 electrotactile tongue displays (Wicab, Inc., Madison, WI) that were delayed by 4 weeks due to a part supply issue and then damaged in shipping which required return to the manufacturer. Prior to the VideoTact unit failure, we were able to determine that the research staff could maintain SA during of a multiple line shape recognition visual task more effectively when using the VideoTact at a zoom level of 75 percent of that presented on the BrainPort®. A design error was detected in a digital interface board related to monitoring of the status of the vibrotactile TTI that did not affect function, but that required fabrication of two small replacement circuit boards to avoid excessive software manipulation to maintain proper mapping with the peripheral vision sensor. We purchased and assembled a number of visual task items to evaluate the potential for testing color perception with blind individuals.

The second quarter efforts included evaluation of modified training protocols by the research staff, hardware modifications to simply operations during the protocol software modification, evaluation of optimal relative field of view between BrainPort® and VideoTact displays for parafoveal functionality. We currently have integrated the current VideoTact signal with our 600 pixel BrainPort® devices. We have integrated a servo controlled color wheel system that mounts in front of the BrainPort® camera and switches between red, blue, green and neutral (clear) filters under user control. This allows a blind (or blindfolded) user to determine the color of the red, green and blue faces of an illuminated cube or button pad. We completed fabrication of a custom frame and curtain system that completely blacks-out the participant testing room ensuring high contrast, low visual noise during training. Following extensive mock up and protocol testing with research staff (see figures 8-10), we completed and submitted an application for use of human research participants to the IHMC institutional review board (IRB).

Figure 7: Research staff testing Landolt "C" orientation test in training room (draped in black felt). Staff member is using the BrainPort® V100 device and wearing the TTI now embedded in an Army Combat Uniform (ACU) tactical vest.

Figure 9: (left) Research staff (wearing TTI vest and using BrainPort®) identifying a golf ball from a baseball. (right) Research staff examining illuminated multicolored cube.

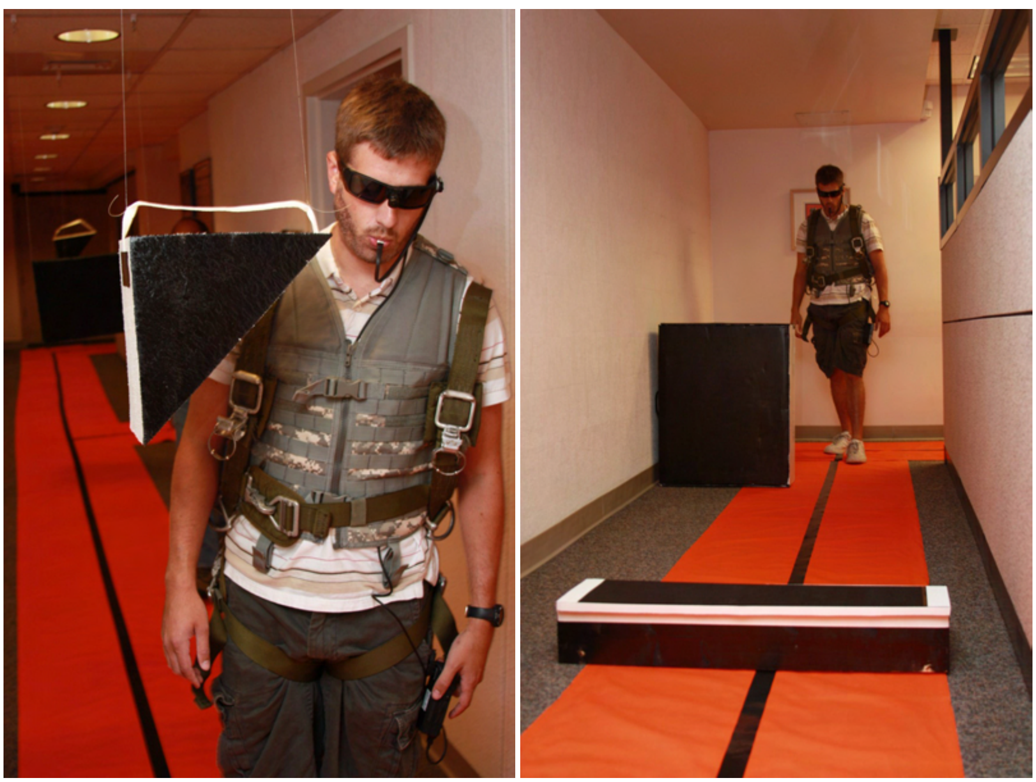

Figure 10: (*left*) Research staff navigating indoor ambulation course while avoiding high contrast foam obstacles suspended from ceiling. (*right*) Research staff navigating a different part of the course with floor level obstacles.

During the third quarter, the research staff practiced the training protocols and improved the user control interface. This included the development of a World Wide Web navigation simulation for the computer based reading/navigation portion of the protocol. This allows us to simulate the interactions participants would have with web-based activities (searching, social networking, etc.) while logging mouse activity, time to find specified links and accuracy when detecting those links. We have completed practice runs through the entire protocol and verified the data collection software (Figure 11).

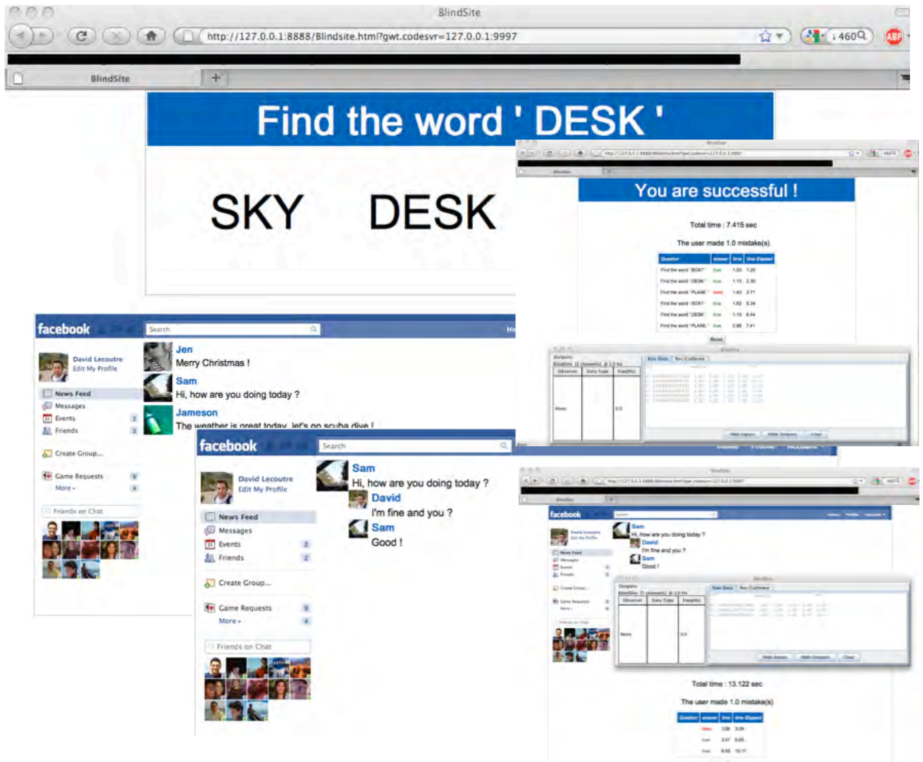

Figure 11: Screenshots from simulated web navigation/reading proficiency task. The test starts with simple tasks such as identifying a word and advances to finding the link for a friend on a Facebook page and clicking through the conversation. The software calculates the number correct and react time for each task. Rather than use a camera to image the monitor, which is the images are sent directly to the ACMI-VAS system from the computer.

We also integrated wireless Playstation3 game console hand controllers (Sony, Corp., Tokyo, Japan) into the ACMI-VAS architecture. These video game interface devices should be familiar to our target population of recently blinded servicemembers and reduce familiarization time. We completed fabrication of the servo controlled red/green/blue/clear color camera filter for the color perception component of the protocol in ABS plastic using IHMC's 3D printer (Figure 12).

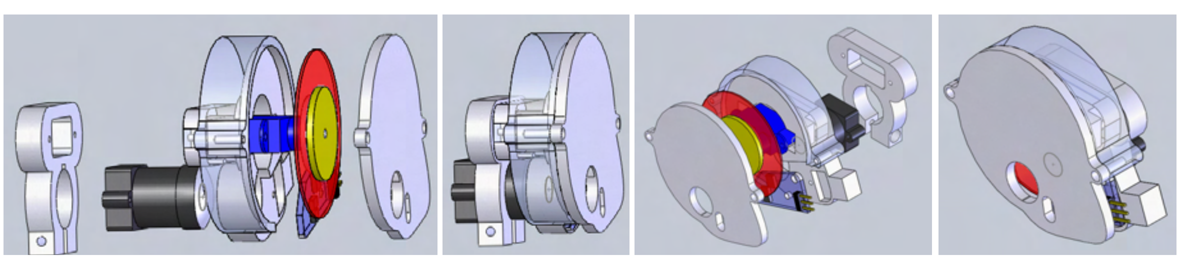

Figure 12: Computer aided design model of removable servo controlled camera color filter and active color sensor.

The color filter was mounted to an unmodified BrainPort® V-100 vision device that has a 400 pixel intraoral display (IOD) and can also be mounted to an earlier BrainPort® Wearable Aid for

Vision Enhancement (BP-WAVE-II) with a 600 pixel IOD. Additionally, we implemented an active color sensor (ColorPAL, Parallax, Inc., Rocklin, CA) to the filter system that provides controlled color illumination for measurement of actual red-green-blue (RGB) values for use with objects that are not self-illuminated. During initial evaluation of this system, the research staff could easily recognize primary colors, as well as secondary colors, presented on a 4x4 array of RGB light emitting diodes (LEDs) mounted under translucent white momentary pushbuttons (Buttonpad ControllerUSB, Sparkfun Electronics, Boulder, CO). Users can, with a slight increase in effort, accurately describe color variations (e.g., reddish orange) (Figure 13).

Figure 13: (*left 6 images*) Research staff using BrainPort® fitted with user controlled RGB filter (white disk mounted to glasses) to identify the color presented on the LED Buttonpad. The "D-Pad" buttons on the Playstation3 game controller allow the user to switch between red, green, blue and clear filters. (right) Integrated hand controller and software (foreground) for color identification task.

In the fourth quarter, we received approval for use of human research participants for the ACMI-VAS protocol from the IHMC IRB. The approval letter was forwarded to the U. S. Army Human Research Protection Office (HRPO), which then requested a number of clarifications and modifications to the previously submitted HRPO application packet. We submitted the requested information as well as additional information as requested by the next level of review. We are currently awaiting HRPO requests for further clarifications or final determination. While awaiting final approval to being subject recruitment, we have rehearsed the protocol with the research staff and made changes and updates to the hardware and software to ensure smooth, consistent protocol execution. This included sewing hook and loop fasteners to the indoor ambulation course runner sections to remove any tripping hazard at the overlapping runner joints and testing placement of ambulation course obstacles. We also verified the functionality of the simulated web browser task as well as the scoring algorithms. Lastly, because the color identification task appears trivial for primary and secondary colors, we have added an additional function that sets one LED on the Buttonpad array to a different color than the other fifteen LEDs. We have determined that blindfolded individuals can quickly identify the background color and both the location and color of the oddball LED accurately. We have also integrated the Button pad and a Playstation3 controller into a single handheld unit that simplifies user interactions with the system (Figure 13, right). The Playstation3 controller portion controls the color filter selection, the ACMI-VAS interfaces (e.g., zoom level, intensity, black/white inversion, etc.) while the button pad displays the colors and detects responses when the user presses the button over the LED. It connects to the control computer as well has the color filter via universal serial bus (USB). This integration of the Playstation3 controller allows the use to manage all of the ACMI-VAS elements with a single hand held device. For the ambulation tasks, which do not require the Button pad display, a standard Playstation3 controller connects wirelessly to the control computer via Bluetooth™. The bulk of the effort on the project this quarter focused on preparing, submitting and revising the IRB applications to the IHMC IRB and the Army HRPO.

Relationship to award Statement of Work

At the end of the first year of the program, we have developed a multisensory interface that provides visual substitution via tactile displays that provides a partial functional restoration of visual perception. Based on the original statement of work, we have completed the following tasks:

Specific Aim # 1: Develop a multi-sensory tactile interface to augment or substitute for recently acquired visual impairment

Task 1. Integrate IHMC Tactile interfaces for haptic retina application

1a. Finalize sensor integration plan for peripheral and central vision functions
1b. Develop integrated abdomen, torso and tongue display mounting system
1c. Develop multiple sensor hardware mounting system
1d. Develop software functional requirements
Milestone #1: ACMI-VAS critical design review

Task 2. Integrate visual sensory augmentation/substitution

2a. Evaluate feasibility of providing stereoscopic vision with current interfaces
2b. Define paracentral display icon for registration of foveation point

Specific Aim #2: Evaluate ACMI-VAS

Task 3. Code software for visual environment interactions

3a. Integrate central (foveal), paracentral and peripheral vision manual controls
3b. Develop calibration procedures for ACMI-VAS
3c. Code user interface
3d. Code performance evaluation interface
3e. Test and evaluate interface function with tactile and audio displays
3f. Define performance metrics and code software for evaluation of metrics
3g. Verify evaluation software functionality
Milestone #3: ACMI-VAS haptic retina evaluation system design complete

Task 4. Demonstration and evaluation

4a. Submit IRB and HRPO applications for use of human research participants
4b. Prototype system functional verification and testing

Remaining Tasks/Milestones:

Task 2. Integrate visual sensory augmentation/substitution

2c. Fabricate hardware for IHMC peripheral vision sensor
2d. Integrate software (using AMI) of IHMC peripheral vision sensor
2e. Test & evaluate ACMI-VAS haptic retina software/hardware integration
Milestone #2: Complete ACMI-VAS haptic retina prototype system

Task 4. Demonstration and evaluation

4c. Identify and recruit 20 recently blinded research participants
4d. Human participant testing
4e. Human participant data analysis
Milestone #4: Collect and analyze ACMI-VAS human research participant data
Milestone #5: Draft manuscript for submission to Ophthalmology (journal)

Deliverables: 1) HRPO application for use of human research participants, 2) Quarterly reports, and 3) Annual Report

Key research accomplishments

- We successfully integrated a prototype haptic retina via the AMI software architecture
- We determined that serial visual tasks such as reading and identifying shapes on a grid was enhanced when using ACMI-VAS
- We determined that colors could be identified tactually.
- We developed a test protocol to evaluate the effectiveness of the ACMI-VAS concept against the BrainPort® V100 alone.

Reportable outcomes

None to date, awaiting HRPO approval to begin human participant testing.

Conclusion

During year one of the ACMI-VAS project, we developed a prototype ACMI-VAS system and the research environment needed to evaluate it. We improved the user control interfaces and developed a method to allow tactual understanding of color. The final portion of this grant will focus on human research participant testing and evaluation, data analysis, drafting a publication detailing the results, and development of the final ACMI-VAS prototype design specification document. The noninvasive nature of the ACMI approach ensures that injured servicemembers could benefit from future upgrades as technologies improve (in out-years) without risks of further surgeries or infection associated with implantable devices. The proposed complementary interface displays can be tailored to suit the needs of an individual. For example, an injury that spared the peripheral vision may only require the higher resolution displays, whereas a condition like hemianopsia might only require a low-resolution spatial awareness component. This proposed technology development will result in a single integrated system prototype capable of providing an alternative mechanism for visual sensing of high resolution foveal vision, low resolution peripheral vision and stabilization of the imagery despite perturbations of the head. Even profoundly blind individuals would benefit from the modularity of the system as they could choose to use specific displays for any given activity. The use of the AMI software agent framework ensures that integration of improvements in any of the major technologies, including sensing devices (e.g., cameras) and interfaces (potentially even implantable ones) will occur quickly, speeding up evaluation of incremental changes and their deployment to the users.

References

Amedi, A., Merabet, L., Bermpohl, F., Camprodon, J., Fox, S., & Pascual-Leone, A. (2005, April). Visual-to-auditory sensory substitution in proficient blind users: Neural correlates and potential application in neuroprostheses research. *Poster presented at AAN 2005, the 57th Annual Meeting of the American Academy of Neurology*, April 9-16, 2005, Miami Beach, Florida, USA.

Bach-y-Rita, P. (1972). *Brain Mechanisms in Sensory Substitution.* New York: Academic Press.

Bach-y-Rita, P. (1995). *Nonsynaptic Diffusion Neurotransmission and Late Brain Reorganization.* New York: Demos-Vermande.

Bach-y-Rita, P., Collins, C. C., Saunders, F., White, B., & Scadden, L. (1969). Vision substitution by tactile image projection. *Nature, 221*, 963-964.

Bavelier, D. & Neville, H. J. (2002). Cross-modal plasticity: Where and how? *Nature Reviews Neuroscience 3*, 443-452.

Boehm, R. (1986). The use of echolocation as a mobility aid for blind persons. *Journal of Visual Impairment and Blindness, 80*(9), 953 – 954.

Bremer, C. D., Pittenger, J. B., Warren, R., Jenkins, J. J., (1977). An illusion of auditory saltation similar to the cutaneous “rabbit”. *American Journal of Psychology 90*(4), 645-654.

Bryant, D., & Bryant, B. (2003). *Assistive Technology for People with Disabilities*. Boston: Pearson Education.

Burton, H., Sinclair, R. J., & McLaren, D. G. (2004). Cortical activity to vibrotactile stimulation: An fMRI study in blind and sighted individuals. *Human Brain Mapping, 23*(4), 210 –228.

Calvert, G. A. (2001). Crossmodal processing in the human brain: Insights from functional neuroimaging studies. *Cerebral Cortex, 11*(12), 1110-1123.

Deiderich, A. (1995). Intersensory facilitation of reaction time: Evaluation of counter and diffusion coactivation models. *Journal of Mathematical Psychology, 39*, 197-215.

Dobelle, W. (2000). Artificial vision for the blind by connecting a television camera to the brain. *American Society for Artificial Internal Organs Journal, 46*(1), 3 – 9.

Endsley, M. R. (2000). Theoretical underpinnings of situation awareness: A critical review. In M. R. Endsley & D. J. Garland (Eds.), *Situation Awareness Analysis and Measurement* (pp. 3-32). Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Fernández, E., Pelayo, F., Romero, S., Bongard, M., Marin, C., Alfaro, A., et al. (2005). Development of a cortical visual neuroprosthesis for the blind: the relevance of neuroplasticity. *Journal of Neural Engineering, 2*(4), R1 - R12.

Finkel, L. H. (1990). A model of receptive field plasticity and topographic map reorganization in the somatosensory cortex. In S. J. Hanson & C. R. Olsen, (Eds.), *Connectionist Modeling and Brain Function: The Developing Interface* (pp. 164-192). Cambridge: MIT Press.

Finney, E. M., Fine, I., Dobkins, K. R. (2001). Visual stimuli activate auditory cortex in the deaf. *Nature Neuroscience, 4*(12), 1171-1173.

Fort, A., Delpuech, C., Pernier, J., & Giard, M.-H. (2002). Dynamics of cortico-subcortical cross-modal operations involved in audio-visual object detection in humans. *Cerebral Cortex, 12*(10), 1031 – 1039.

Foxe, J. J., Morocz, I. A., Murray, M. M., Higgins, B. A., Javitt, D. C., & Schroeder, C. E. (2000). Multisensory auditory–somatosensory interactions in early cortical processing revealed by high-density electrical mapping. *Cognitive Brain Research, 10*, 77 – 83.

Gaudissart, V., Ferreira, S., Thillou, C., & Gosselin, B. (2005, September). *Sypole: A mobile assistant for the blind.* Proceedings of the 13th European Signal Processing Conference, September 4-8, Antalya, Turkey.

Ifukube, T., Sasaki, T., & Peng, C. (1991). A blind mobility aid modeled after echolocation of bats. *IEEE Transactions on Biomedical Engineering, 38*(5), 461 – 465.

Javaheri, M., Hahn, D. S., Lakhanpal, R. R., Weiland, J. D., & Humayun, M. S. (2006). Retinal prostheses for the blind. Annals of Academic Medicine Singapore, 35, 137 – 144.
Johnson, J. A., & Zatorre, R. J. (2005). Attention to simultaneous unrelated auditory and visual events: Behavioral and neural correlates. *Cerebral Cortex, 15*(10), 1609 -1620.
Jones, J. A., & Callan, D. E. (2003). Brain activity during audiovisual speech perception: An fMRI study of the McGurk effect. *Neuroreport, 14*(8), 1129-1133.
Kaczmarek, K., Bach-y-Rita, P., Tompkins, W. J. & Webster, J. G. (1985). A tactile vision-substitution system for the blind: Computer-controlled partial image sequencing. *IEEE Transactions on Biomedical Engineering, BME-32*, 602-608.
Kanwisher, N., & Wojciulik, E. (2000). Visual attention: Insights from brain imaging. *Nature Reviews Neuroscience, 1*, 91 – 100.
Kotler, S. (2002, September). Vision quest: A half century of artificial-sight research has succeeded. And now this blind man can see. *Wired, 10*(9). Retrieved November 18, 2008 from http://www.wired.com/wired/archive/10.09/vision_pr.html
Kupers R., Fumal, A., de Noordhout, A. M., Gjedde, A., Schoenen, J., & Ptito, M. (2006). Transcranial magnetic stimulation of the visual cortex induces somatotopically organized qualia in blind subjects. *Proceedings of the National Academy of Science, USA, 103*(35), 13256-13260.
Land, E. H. (1964). The retinex. *American Scientist, 52*(2), 247 – 264.
Laurienti, P. J., Burdette, J. H., Wallace, M. T., Yen, Y. F., Field, A. S., & Stein, B. E. (2002). Deactivation of sensory-specific cortex by cross-modal stimuli. *Journal of Cognitive Neuroscience, 14*(3), 420 – 429.
Loose, R., Kaufmann, C., Auer, D. P., & Lange, K. W. (2003). Human prefrontal and sensory cortical activity during divided attention tasks. *Human brain mapping, 18*(4), 249 – 259.
Machts, L. (1920). Device for converting light effects into effects perceptible by blind persons. German patent 326283.
Maynard, E. M., Nordhausen, C. T., & Normann, R. A. (1997) The Utah intracortical electrode array: A recording structure for potential brain-computer interfaces. *Electroencephalography and Clinical Neurophysiology, 102*, 228 – 239.
Meijer, P. B. L. (1992). An experimental system for auditory image representations. *IEEE Transactions on Biomedical Engineering, 39*(2), 112-121. Reprinted in the *1993 IMIA Yearbook of Medical Informatics*, pp. 291-300.
Meredith, M. A., & Stein, B. E. (1986). Visual, auditory, and somatosensory convergence on cells in superior colliculus results in multisensory integration. *Journal of Neurophysiology, 56*, 640-662.
Moço, V., & Archambault, D. (2004, July). Automatic conversions of mathematical Braille: A survey of main difficulties in different languages. *Proceedings of the 9th International Conference on Computers Helping People with Special Needs, 3118*, 638-643.
Mozolic, J. L., Joyner, D., Hugenschmidt, C. E., Peiffer, A. M., Kraft, R. A., Maldjian, J. A., Laurienti, P. J. (2008). Cross-modal deactivations during modality-specific selective attention. *BioMed Central: Neurology, 8*. Retrieved November 25, 2008 from http://www.biomedcentral.com/1471-2377/8/35
Owens, D. E. (2008, May 4). Blindness becomes bitter legacy for many veterans. *The Orlando Sentinel*, pp. A1.
Paivio, A. (1991). Dual Coding Theory: Retrospect and current status. *Canadian Journal of Psychology, 45*(3), 255-287.
Ptito, M., Moesgaard, S. M., Gjedde, A., & Kupers, R. (2005). Cross-modal plasticity revealed by electrotactile stimulation of the tongue in the congenitally blind. *Brain, 128*(3), 606-614.

Raj, A. K., Kass, S. J., & Perry, J. F. (2000). Vibrotactile displays for improving spatial awareness. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, San Diego, CA*, I:181-184.

Rauschecker, J. P. & Shannon, R. V. (2002) Sending Sound to the Brain. *Science (295)*557: 1025-1029.

Reefhuis, J., Honein, M. A., Whitney, C. G., Chamany, S., Mann, E. A., Biernath, K. R., et al. (2003). Risk of bacterial meningitis in children with cochlear implants. *New England Journal of Medicine, 349*, 435-445.

Sadato, N., Okada, T., Kubota, K., & Yonekura, Y. (2004). Tactile discrimination activates the visual cortex of the recently blind naive to Braille: A functional magnetic resonance imaging study in humans. *Neuroscience Letters, 359*(1-2), 49 – 52.

Sadato, N., Pascual-Leone, A., Grafman, J., Ibanez, V., Deiber, M. P., Dold, G., & Hallett, M. (1996). Activation of the primary visual cortex by Braille reading in blind subjects. *Nature, 380*, 526 –528.

Sathian, K. (2005). Visual cortical activity during tactile perception in the sighted and the visually deprived. *Developmental Psychobiology, 46*(3), 279-286.

Saunders, F. A., Hill, W. A., & Franklin, B. (1981). A wearable tactile sensory aid for profoundly deaf children. *Journal of Medical Systems, 5*, 265-270.

Schroeder, C. E., & Foxe, J. (2005). Multisensory contributions to low-level, 'unisensory' processing. *Current Opinion in Neurobiology, 15*, 454-458.

Veraart, C., Wanet-Defalque, M. C., Gerard, B., Vanlierde, A., & Delbeke, J. (2003). Pattern recognition with the optic nerve visual prosthesis. *Artificial Organs, 27*, 996 – 1004.

Walcott, E. C., & Langdon, R. B. (2001). Short-term plasticity of extrinsic excitatory inputs to neocortical layer 1. *Experimental Brain Research, 136*, 143 – 151.

Wallace, M. T., & Stein, B. E. (2000). Onset of cross-modal synthesis in the neonatal superior colliculus is gated by the development of cortical influcences. *The Journal of Neurophysiology, 83*(6), 3578-3582.

van Wassenhove, V., Grants, K. W., Poeppel, D. (2005). Visual speech speeds up the neural processing of auditory speech. *Proceedings of the National Academy of Sciences, 102*(4), 1181-1186.

Weiland, J. D., Liu, W., & Humayun, M. S. (2005). Retinal prosthesis. Annual Review of Biomedical Engineering. 7, 361 – 401.

Wickens, C. D., & Holland, J. (1999). *Engineering psychology and human performance* (3rd ed.). Upper Saddle River, NJ: Prentice Hall, Inc.

Yu, W., Kuber, R., Murphy, E., Strain, P. & McAllister, G. (2006) A novel multimodal interface for improving visually impaired people's web accessibility. *Virtual Reality, 9*(2), 133 – 148.

Zhou, D., & Greenberg, R. (2005). Microsensors and microbiosensors for retinal implants. *Frontiers in Bioscience, 10*, 166-179.

Zrenner, E., Bartz-schmidt, K. U., Benav, H., Besch, D., Bruckmann, A., Gabel, V,…Wilke, R. (2010). Subretinal electronic chips allow blind patients to read letters and combine them into words. *Preceedings of the Royal Society Biological Sciences,* 1-9.

Appendix: Acronyms

- ACMI-VAS – Anthro-Centric Multisensory Interface for Vision Augmentation/Substitution
- AMI – Adaptive Multiagent Integration
- BP-WAVE II– BrainPort® Wearable Aid for Vision Enhancement, version II
- HRPO – Human Research Protection Office
- IHMC – Florida Institute for Human and Machine Cognition
- IOD – Intra Oral Device
- IRB – Institutional Review Board
- JAWS – Job Access With Speech
- LED – Light Emitting Diode
- NASA – National Aeronautics and Space Administration
- RGB – Red, Green, Blue
- SA – Situation Awareness
- TBI – Traumatic Brain Injury
- TSAS – Tactile Situation Awareness System
- TTI – Tactile Torso Interface
- USB – Universal Serial Bus